

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

# Accelerator Neutrinos in the 21<sup>st</sup> Century

## BUE-CTP International Conference on Neutrinos in the LHC Era, Luxor, Nov 15-19, 2009

Mary Bishai  
Brookhaven National Laboratory

November 13, 2009

# Outline

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

- 1 Accelerator neutrinos and neutrino mixing**
- 2 Short baseline accelerator expts**
- 3 CP violation and the mass hierarchy**
- 4 Future long baseline expts**
  - DUSEL/LBNE
  - Neutrino Expts. in Japan
  - Superbeams in Europe
- 5 Summary**

# Discovery of Neutrino Flavor

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

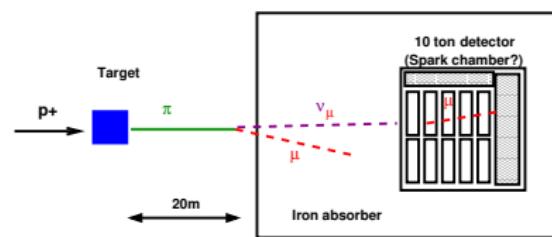
Summary



**1962: Leon Lederman, Melvin Schwartz and Jack Steinberger use BNL's Alternating Gradient Synchrotron (AGS) to produce a beam of neutrinos using the decay  $\pi^+ \rightarrow \mu^+ \nu_\mu$**



The AGS



Making  $\nu$ 's

**Result: 40 neutrino interactions recorded in the detector, 6 of the resultant particles were identified as background and 34 identified as  $\mu \Rightarrow \nu_x = \nu_\mu$**

***The first accelerator neutrino experiment was at the AGS.***

# Neutrino Mixing

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

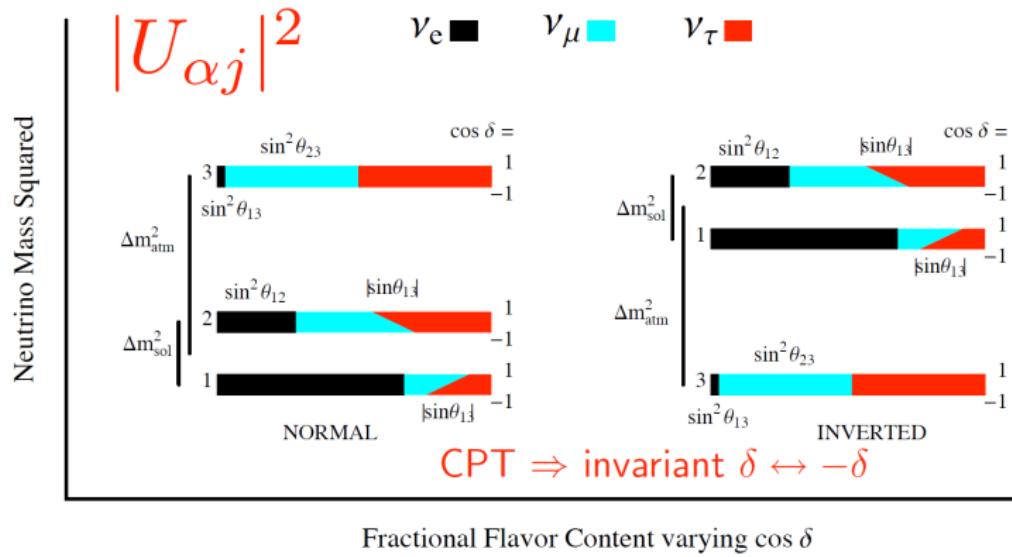
Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe  
Summary



$\sin^2 \theta_{13}$ : Amount of  $\nu_e$  in  $\nu_3$

$\tan^2 \theta_{12}$ :  $\frac{\text{Amount of } \nu_e \text{ in } \nu_2}{\text{Amount of } \nu_e \text{ in } \nu_1}$

$\tan^2 \theta_{23}$ : Ratio of  $\frac{\nu_\mu}{\nu_\tau}$  in  $\nu_3$

**WE DONT KNOW:  $\sin^2 2\theta_{13}$ ,  $\delta_{\text{cp}}$ ,  $\text{sign}(\Delta m_{31}^2)$**

# Measuring neutrino mixing - $\nu_e$ oscillations

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

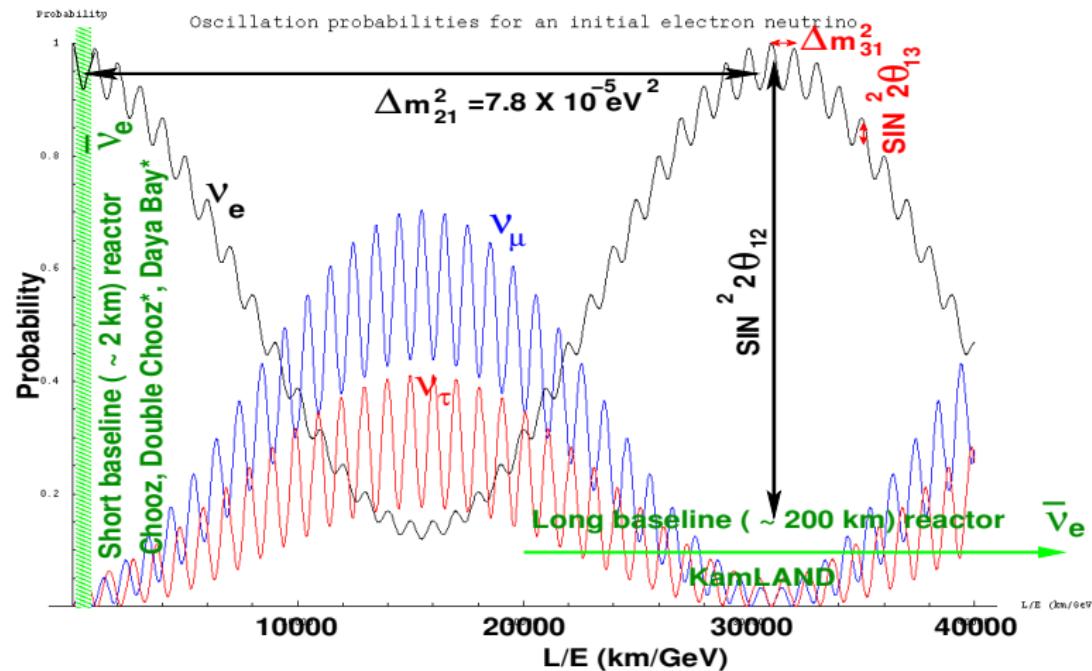
CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan

Superbeams in  
Europe

Summary

Solar  $\nu_e$  disappearance constrained  $1 \rightarrow 2$  mixing. Precision from reactor  $\bar{\nu}_e$  experiments:

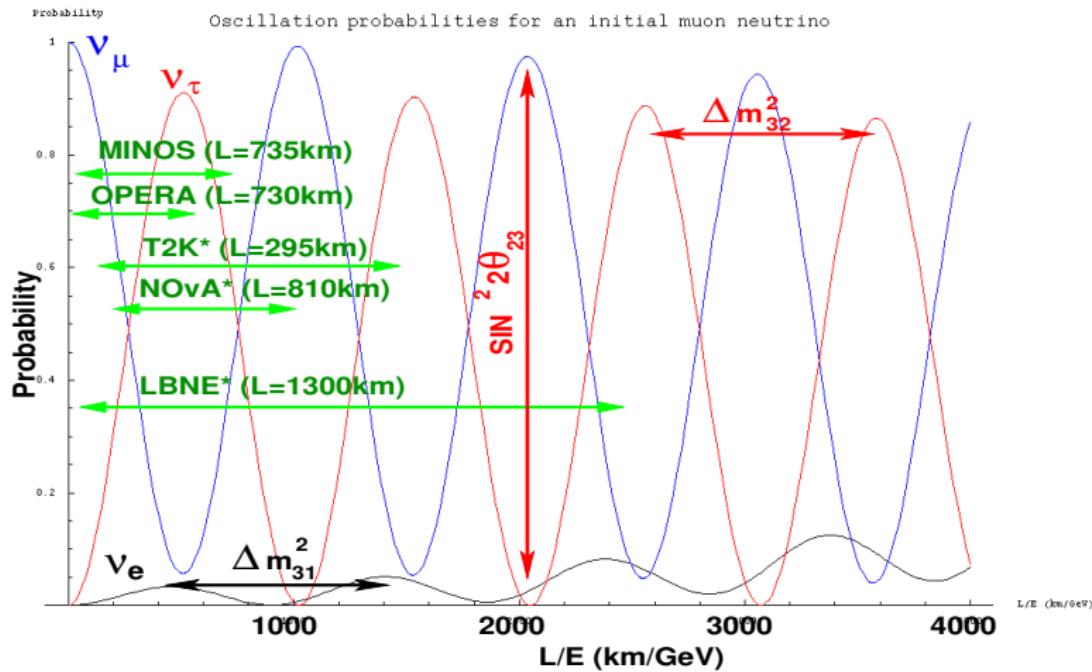


\* = future reactor  $\bar{\nu}_e$  experiments

# Measuring neutrino mixing - $\nu_\mu$ oscillations

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Accelerator  
neutrinos and  
neutrino  
mixing



\* = future accelerator  $\nu_\mu$  experiments

**SuperK atmospheric  $\nu_\mu$  disappearance ( $L/E = 3 \rightarrow 30,000$ ) probes 2  $\rightarrow$  3 oscillations** (talks by Yang, Raaf).

# Early 21<sup>st</sup> Century Neutrino Beam: NuMI

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

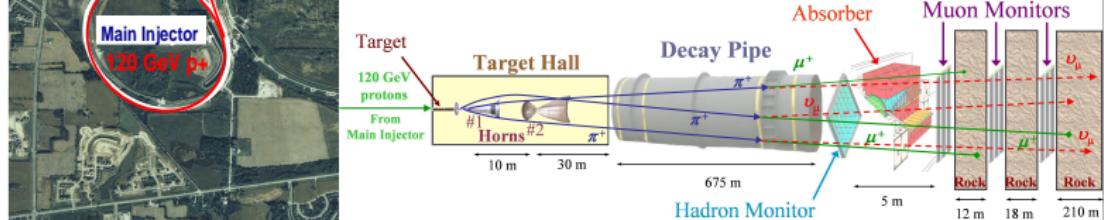
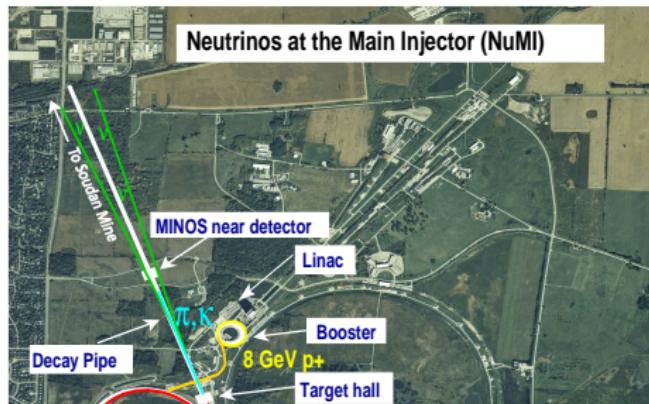
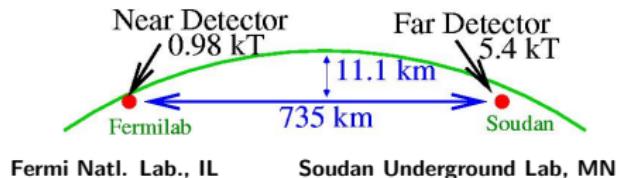
Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



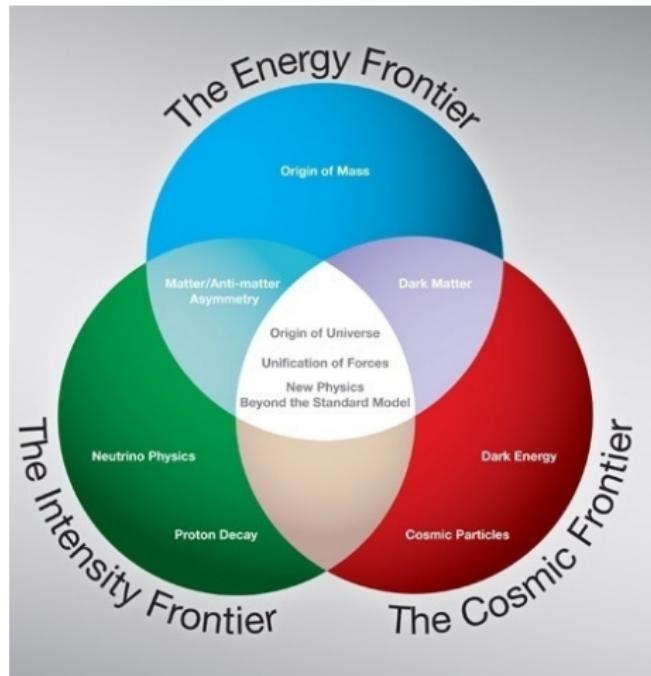
NuMI Horn 2 inner conductor  
Radial field,  $B \propto 1/r$

3T at 200 kA

# Accelerator Neutrinos and LHC: The Intensity Frontier

# Accelerator Neutrinos in the 21<sup>st</sup> Century

Accelerator  
neutrinos and  
neutrino  
mixing



# The mixing matrix - 2009

J. Valle, TAUP '09

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

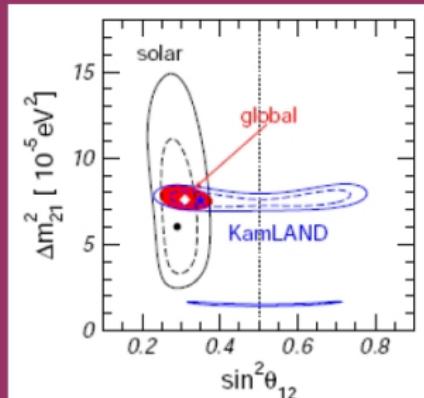
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

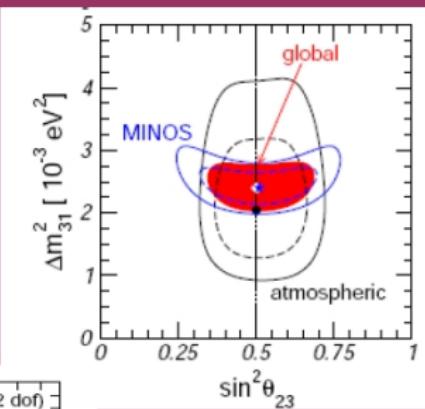
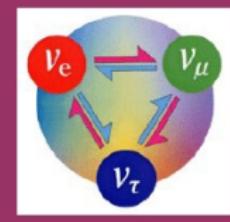
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

Maltoni et al, NJP 6 (2004) 122



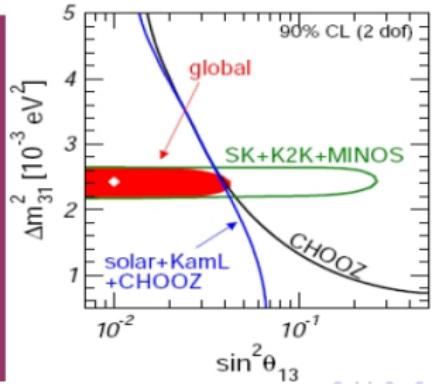
Schwetz et al, NJP 10 (2008) 113011



Homestake, SAGE+  
GALLEX/GNO,  
Super-K, SNO  
Borexino

KamLAND (180 Km)

Valle@TAUP09



... Super-K

K2K (250 Km)  
MINOS (735 Km)

# $\theta_{13}$ by 2016

M. Mezzetto, arXiv:0905.2842

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

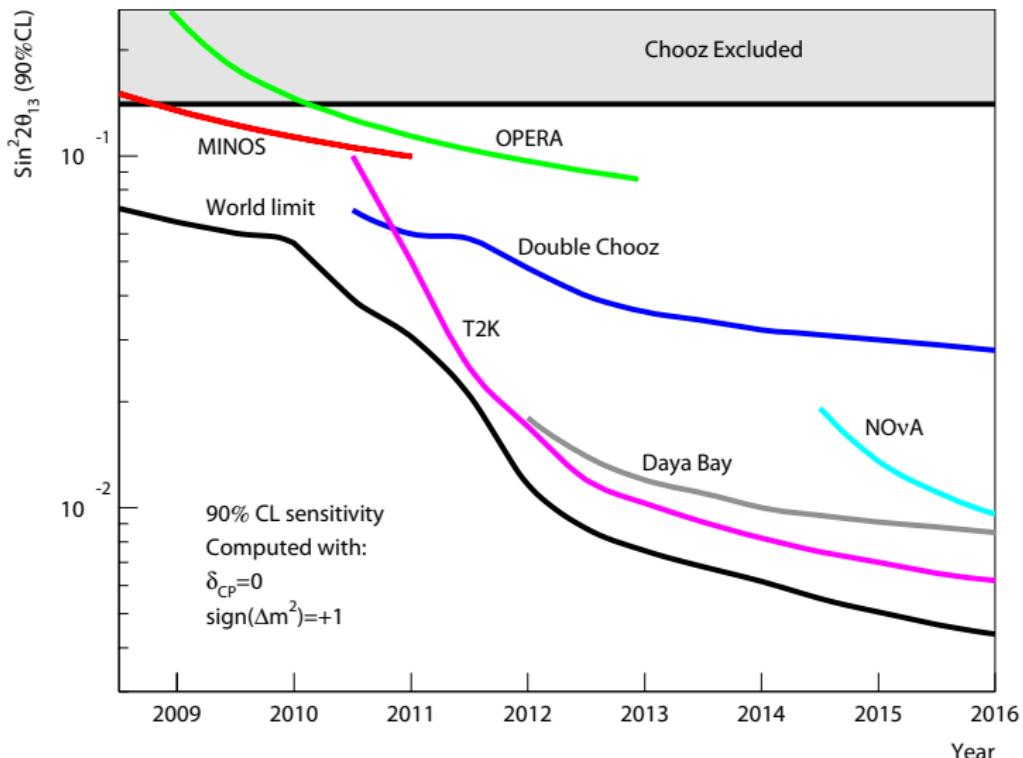
CP violation  
and the mass  
hierarchy

Future long  
baseline expts

DUSEL/LBNE  
Neutrino Expts.  
in Japan

Superbeams in  
Europe

Summary



# The MiniBoone Experiment

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

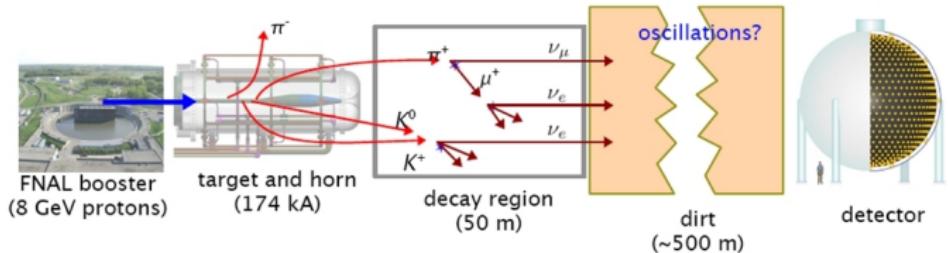
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

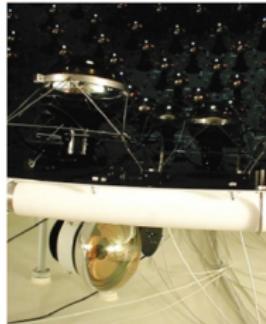
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

## The MiniBooNE design strategy...must make $\nu_\mu$



- Start with 8 GeV proton beam from FNAL Booster
- Add a 174 kA pulsed horn to gain a needed  $\times 6$
- Requires running  $\nu$  (not anti- $\nu$ ) to get flux
- Pions decay to  $\nu$  with  $E_\nu$  in the 0.8 GeV range
- Place detector to preserve LSND L/E:  
 MiniBooNE: (0.5 km) / (0.8 GeV)  
 LSND: (0.03 km) / (0.05 GeV)
- Detect  $\nu$  interactions in 800T pure mineral oil detector  
 1280 inner PMT's and 240 Veto PMT's  
 ~10% reconstruction energy resolution



Data collected: 6.5E20 POT in neutrino and 3.4E20 POT in antineutrino mode

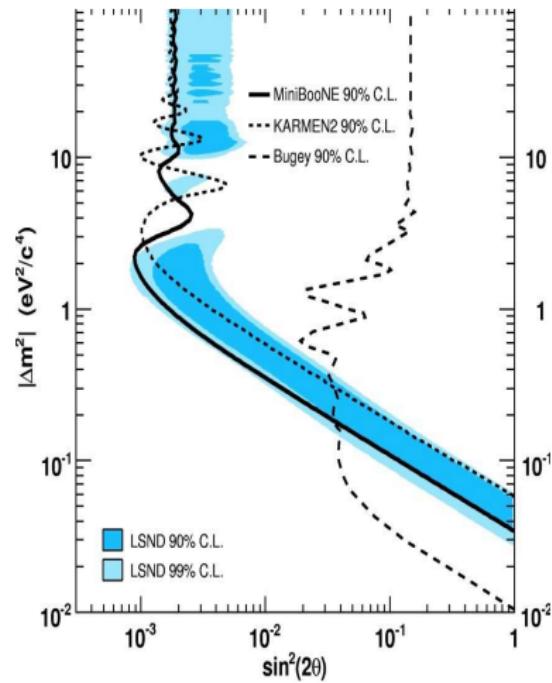
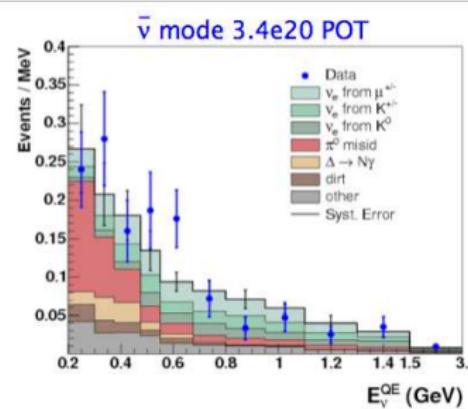
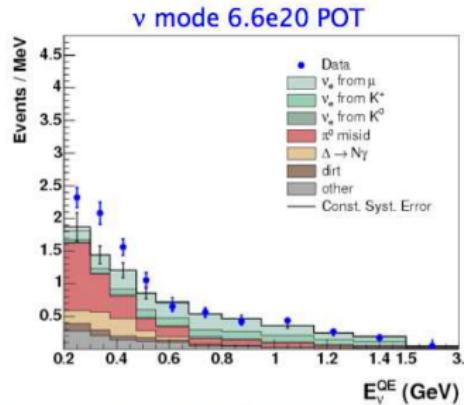
NIST

Los Alamos

## MiniBoone $\nu_e$ Appearance Results

# Accelerator Neutrinos in the 21<sup>st</sup> Century

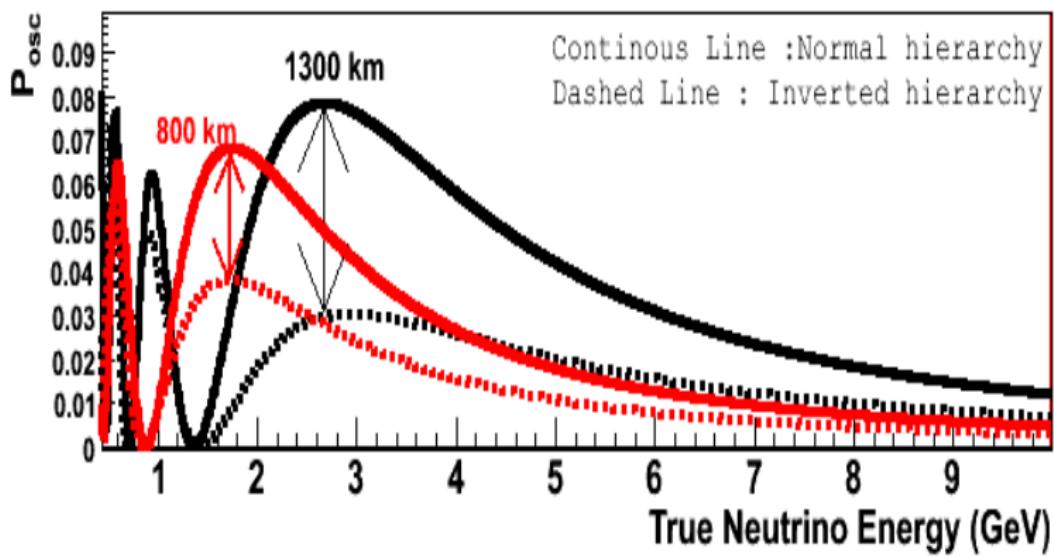
## Short baseline accelerator expts



## Measurements of the Mass Hierarchy

# Accelerator Neutrinos in the 21<sup>st</sup> Century

CP violation  
and the mass  
hierarchy



# CP Violation, Mass Hierarchy and $\nu_\mu \rightarrow \nu_e$

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

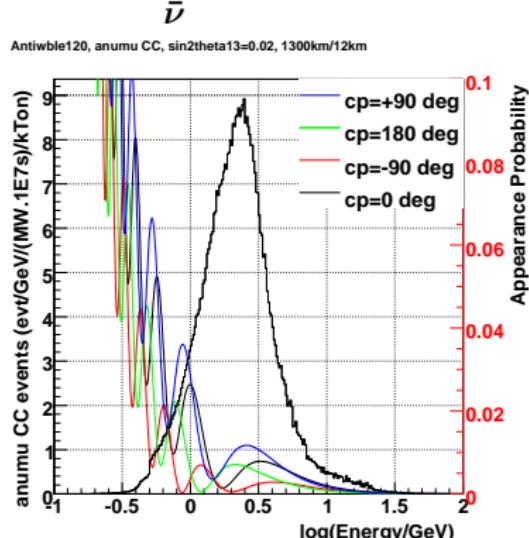
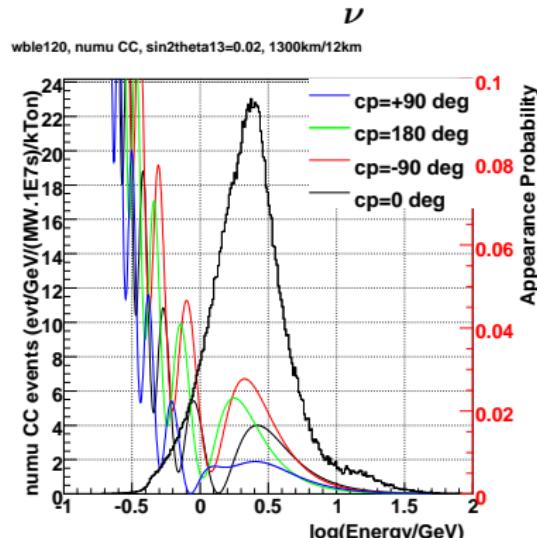
CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

*Appearance probabilities of  $\nu_\mu \rightarrow \nu_e$  for different values of the CP phase.  
A CP phase  $\neq 0, \pi$  implies CP is violated in the lepton sector.*

## Normal Hierarchy



**CP effects largest  $E_\nu < 3$  GeV.**

# CP Violation, Mass Hierarchy and $\nu_\mu \rightarrow \nu_e$

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

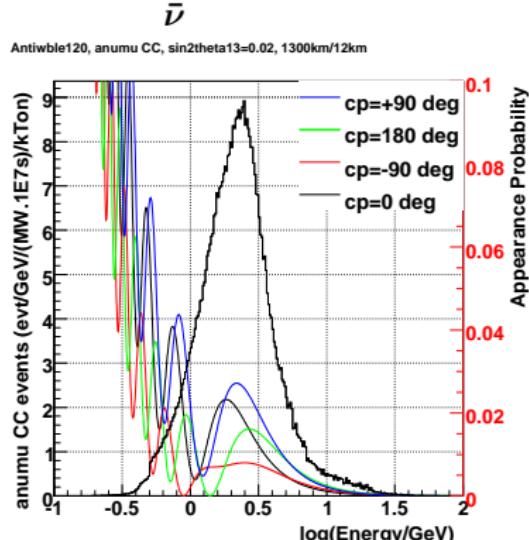
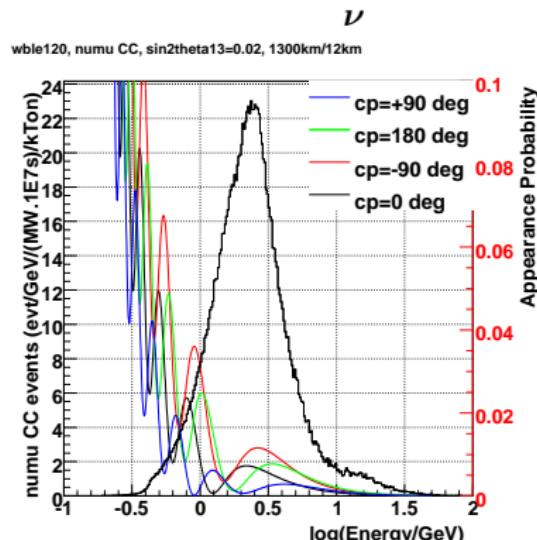
CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

*Apearance probabilities of  $\nu_\mu \rightarrow \nu_e$  for different values of the CP phase.  
A CP phase  $\neq 0, \pi$  implies CP is violated in the lepton sector.*

## Reversed Hierarchy



Matter effects large  $E_\nu > 1.5$  GeV.

# $\theta_{13}$ and CPV

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

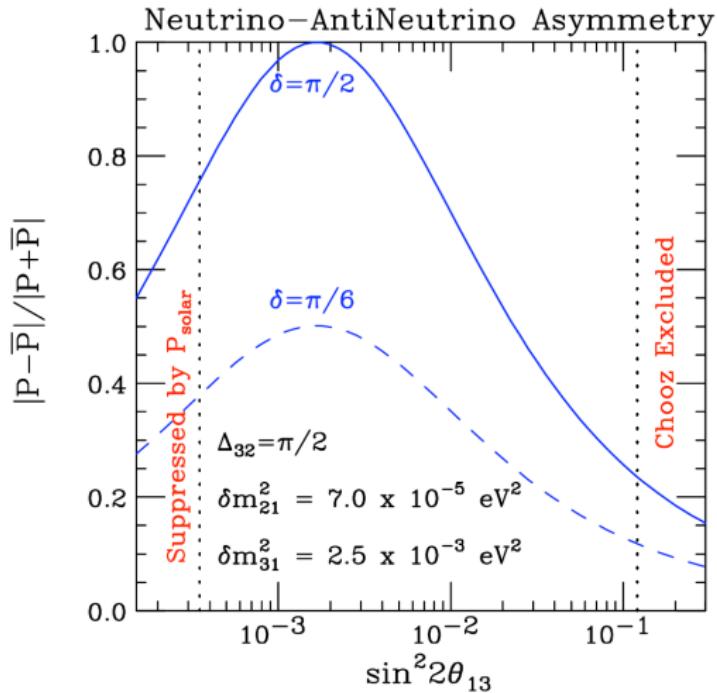
Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



# Physics sensitivity vs baseline

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

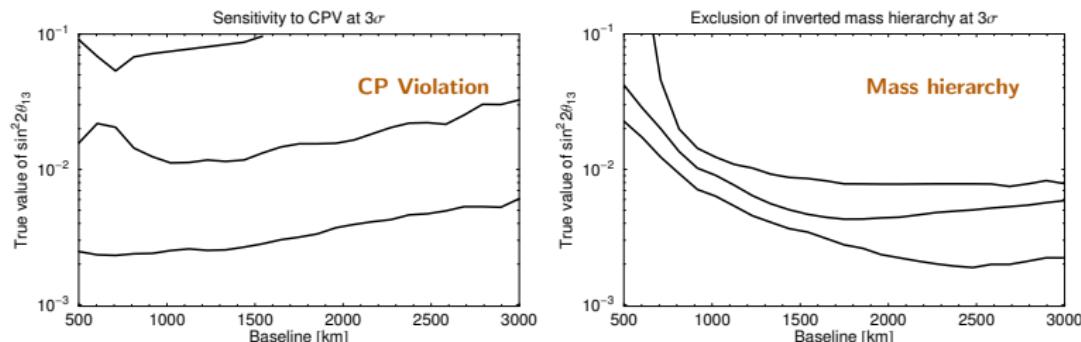
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

Using a broad-band beam with a peak interaction rate at 2 GeV,  
 $\text{FWHM}=3 \text{ GeV}$ , a parameterized water Cerenkov detector and  
exposure of  $5 \text{ MW.yr} (\nu) + 10 \text{ MW.yr} (\bar{\nu})$  (V. Barger *et al.*. Phys. Rev. D 74,  
073004 2006):



Minimum value of  $\sin^2(2\theta_{13})$  for which the sensitivity is  $> 3\sigma$   
for (best, 50%, worst) of  $\delta_{\text{cp}}$  values

Longer baselines = larger mass effects

Best sensitivity is for baselines 1200 - 2500km

# Deep Underground Science and Engineering Laboratory

*July 10, 2007: the National Science Foundation (NSF) selected the University California-Berkeley to produce a technical design for DUSEL at Homestake Mine, SD*

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

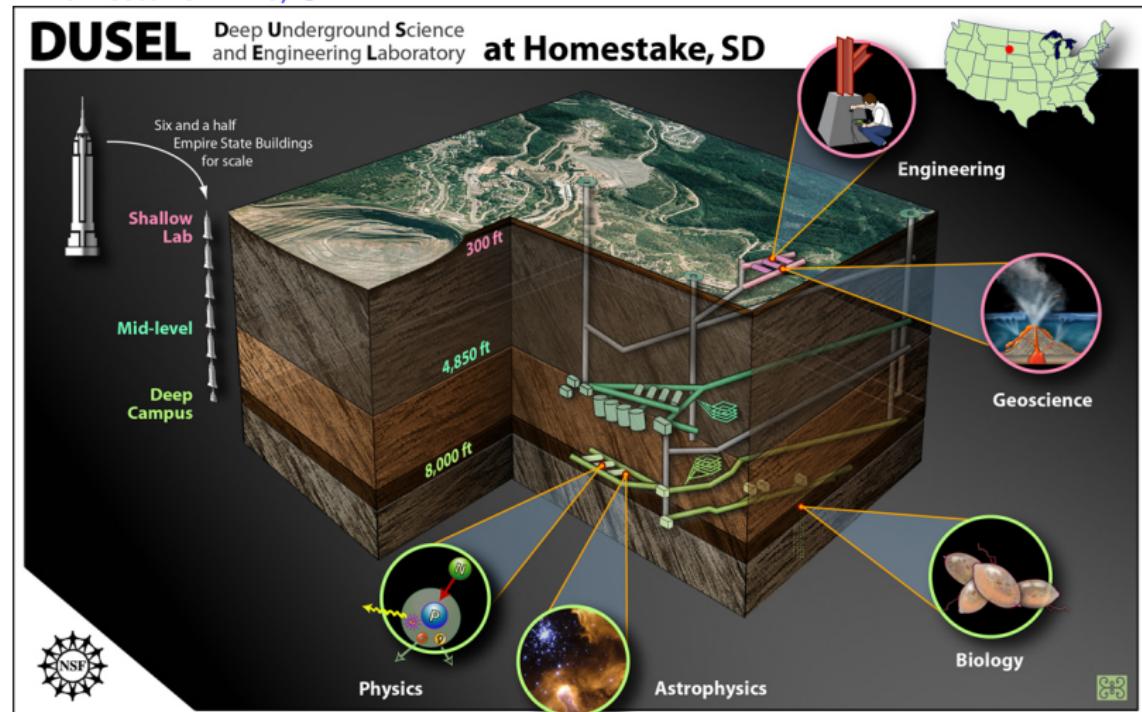
Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



# DUSEL Timeline

J. Dehmer HEPAP Feb, 2009

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

## DUSEL Working Timeline

- July '08: Internal project review of facility & infrastructure.
- January '09: NSF Project Review #1.
- January '10: NSF Project Review #2.
- December '10: NSF Preliminary Design Review (PDR).
  - Project readiness, plan will be assessed at this milestone.
- Spring '11: Presentation of DUSEL MREFC package to NSB.
- FY13: Earliest construction funding (MREFC) start, if approved.

Planning with potential partners (DOE, international, etc.)  
being integrated into above schedule.

# Fermilab Neutrino Beams: Future

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

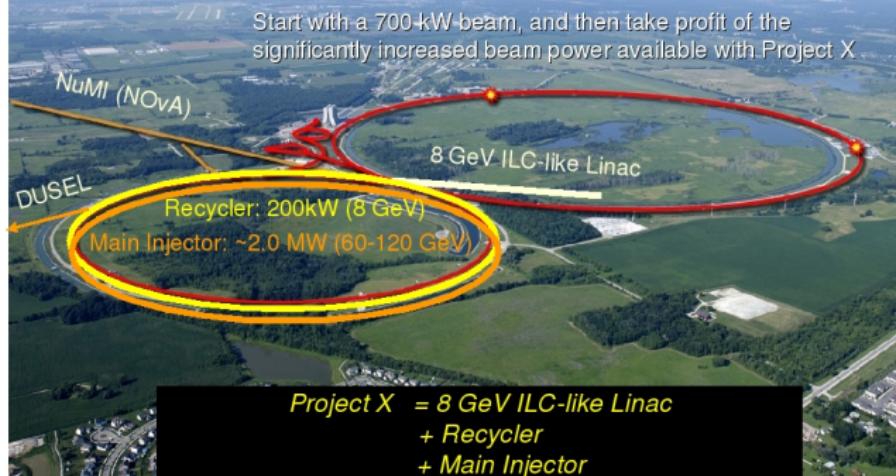
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

**The NuMI beamline uses a 300kW proton beam from the Main Injector (700 kW by 2012).**

**NuMI is the most powerful  $\nu$  beamline operating today .**

## Fermilab vision :The Intensity Frontier with Project X:



**The proposed Project X at FNAL can produce 2MW**

# The Long Baseline Neutrino Experiment

*A Long Baseline Neutrino Experiment (LBNE) from Fermilab to megaton scale detectors at Homestake is now being designed. CDR late 2010.*

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

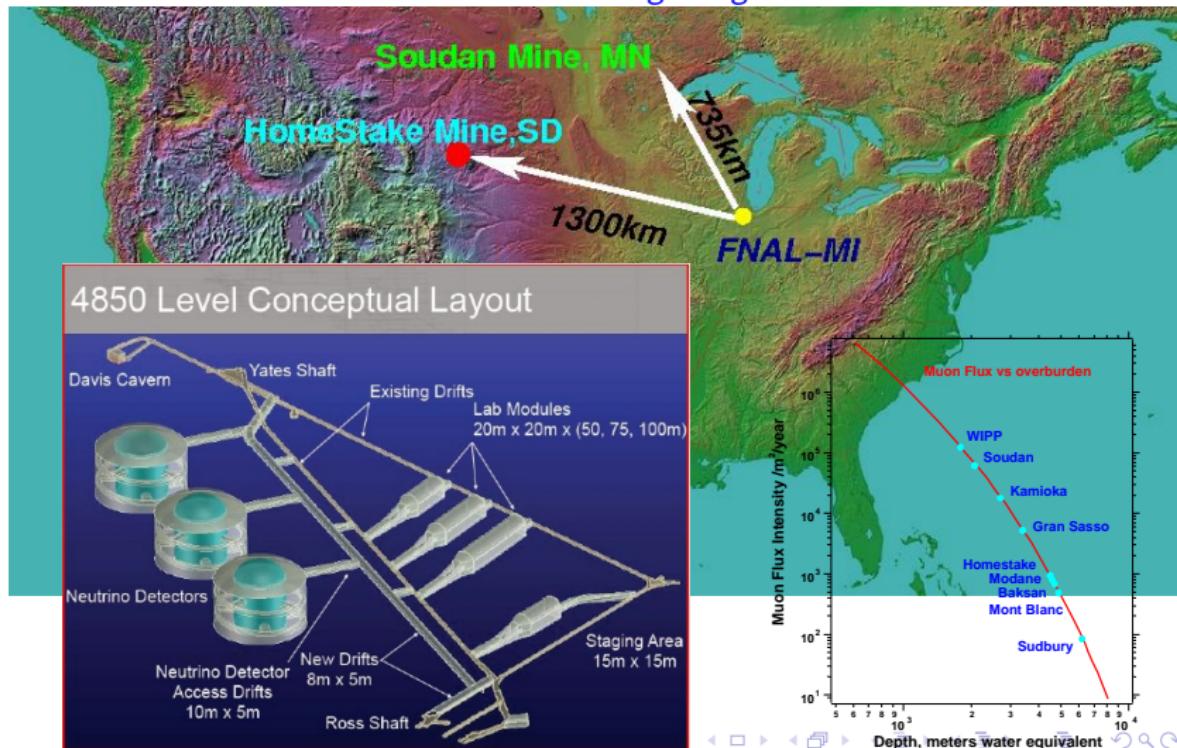
Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



# The LBNE Collaboration

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



Collaboration meeting 2/26-2/28, 2009 at UC Davis, CA

# DUSEL Detectors: Water Cerenkov

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

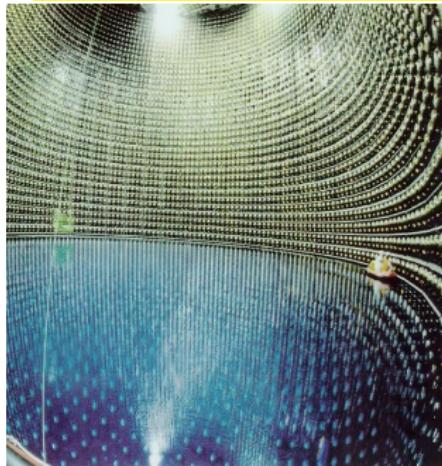
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

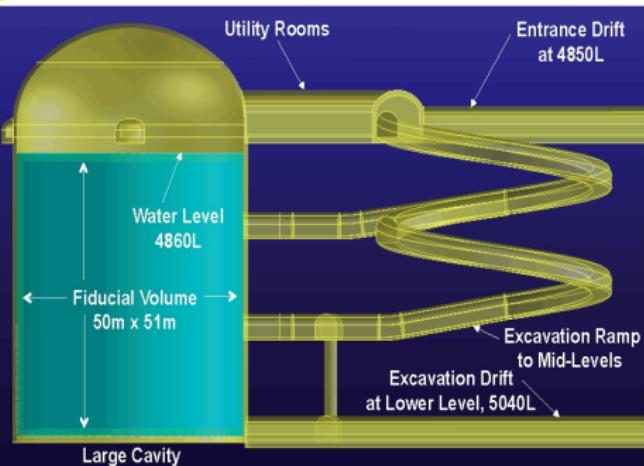
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

SuperKamiokande : 50kT



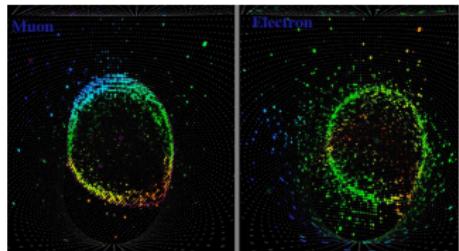
DUSEL WCe Module : ~ 120 kT



3 100kT (fiducial) modules,  $\approx 55\text{m}$  diameter,  $\approx 60\text{m}$  height, 60K 10"  
PMTs/module (25% coverage)

Known technology 2 – 3× SuperK

Higher backgrounds, low efficiency



# DUSEL Detectors: Liquid Argon TPC

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

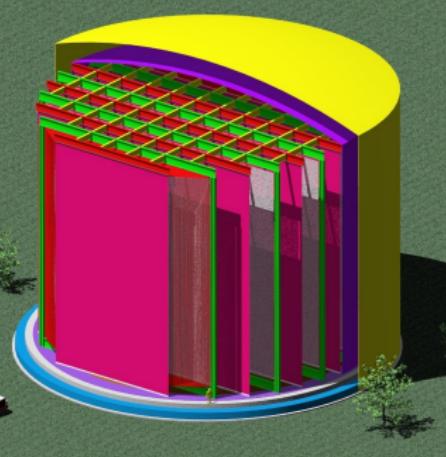
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

**ICARUS module : 0.3kT**



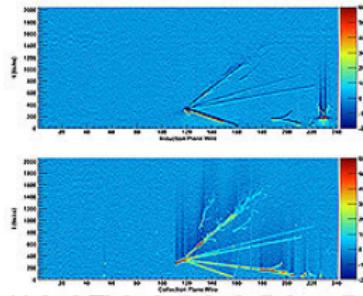
**DUSEL LAr : 50 kT**



**ArgoNeuT (175 litre) prototype in the  
NuMI beam →**

**High efficiency and purity**

**Requires 100× scale-up - unproven.**

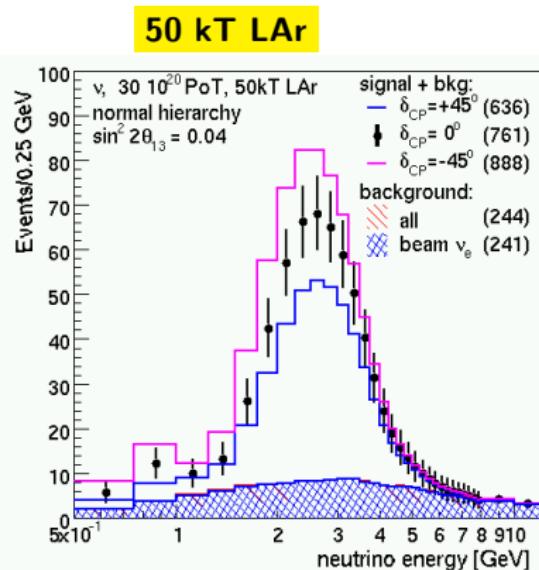
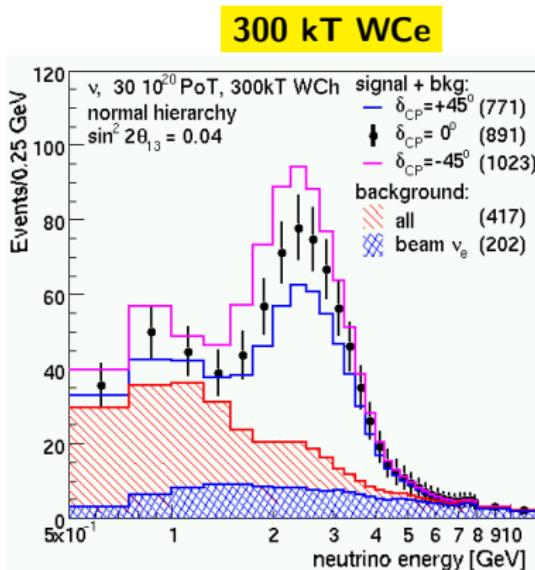


## LBNE/DUSEL spectra and event rates

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

DUSEL/LBNE  
Neutrino Expts.  
in Japan

A preliminary on-axis wide-band beam for LBNE based on the NuMI focusing system has been developed. Water Cerenkov response is based on the SuperK MC. LAr is modeled as a near-perfect detector. Exposure is 3 MW. yr  $\nu$  with  $\sin^2 2\theta_{13} = 0.04$ ,  $\delta_{cp} > 0$ ,  $m_3 > m_1$



# Measurements of $\delta_{\text{cp}}$ in LBNE

Mark Dierckxsens

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

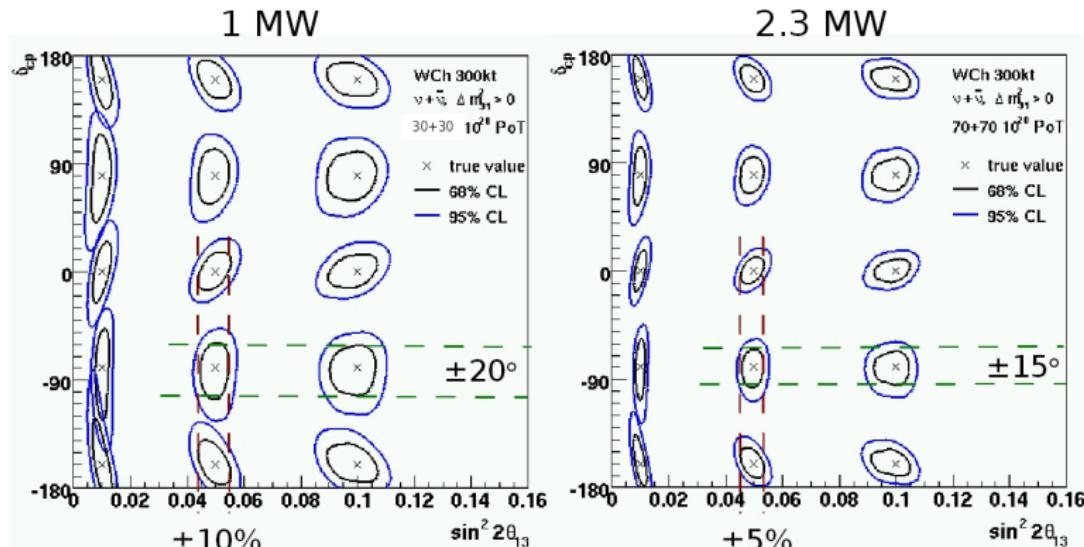
CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

with a 300 kT WCe detector and 3 yrs of  $\nu$  + 3 yrs of  $\bar{\nu}$  running:

## ( $\theta_{13}, \delta_{\text{cp}}$ ) Measurement



Precision measurement of  $\delta_{\text{cp}}$  for  $\sin^2 2\theta_{13} \geq 0.01$

# DUSEL Sensitivities

WCe, 2.3MW beam, 3 yrs  $\nu$  + 3 yrs  $\bar{\nu}$

Accelerator  
Neutrinos in  
the 21st  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

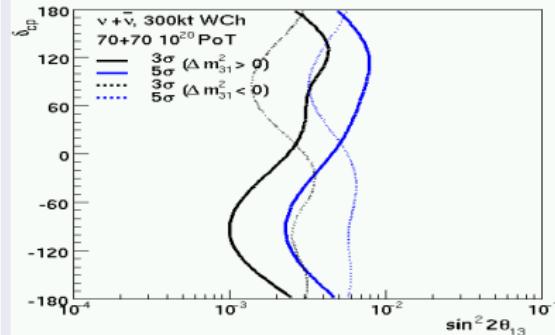
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

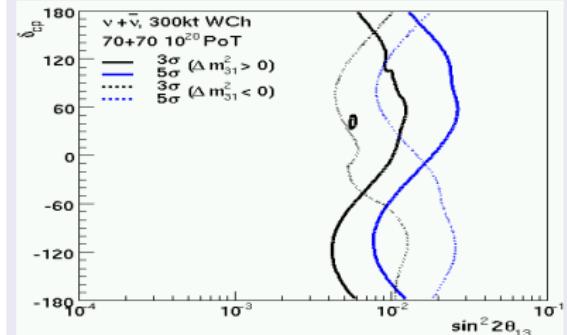
Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

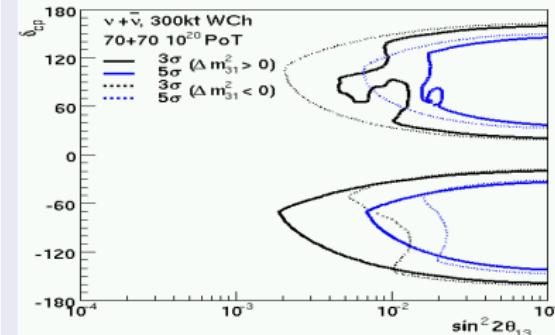
$\theta_{13} @ 3.5 \sigma$



Mass hierarchy @ 3.5  $\sigma$



CP violation @ 3.5  $\sigma$



Summary of sensitivities

The smallest value of  $\sin^2 2\theta_{13} @ 3\sigma$ :

$\theta_{13} \neq 0$	$\text{sign}(\Delta m^2)$	CPV
all $\delta_{cp}$	0.014	0.012

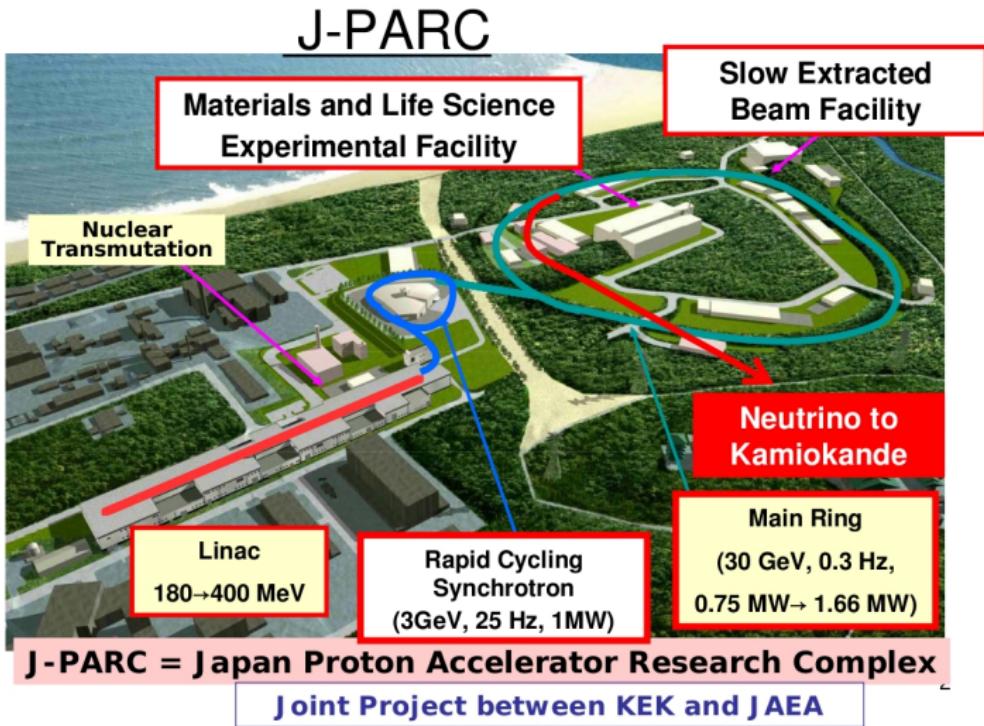
Mark Dierckxens, APS 09

## Long Baseline Projects in Japan

from talk by Koichiro Nishikawa, KEK

# Accelerator Neutrinos in the 21<sup>st</sup> Century

Future long  
baseline expts.  
DUSEL/LBNE  
Neutrino Expts.  
in Japan



# 3 Long Baseline Scenarios

from talk by Koichiro Nishikawa, KEK

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



## Three Possible Scenario Studied at NP08 Workshop



# Sensitivities of Scenario 3

from talk by Koichiro Nishikawa, KEK

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

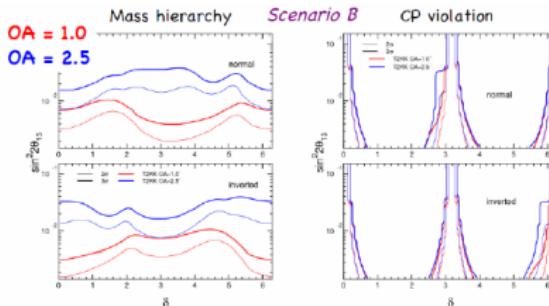
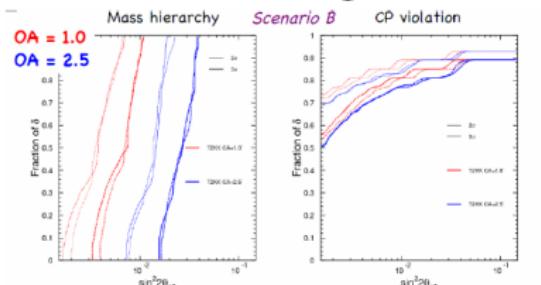
CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

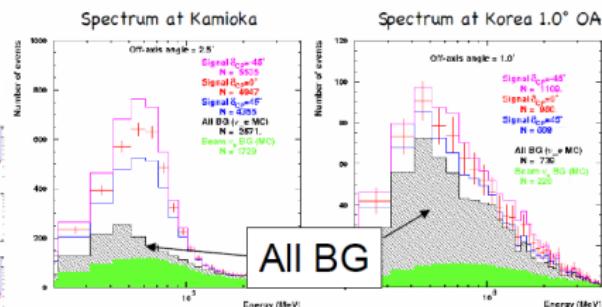
Summary

- Cover 2<sup>nd</sup> Maximum @ Korea
- Cover 1<sup>st</sup> Maximum @ Kamioka
- 5 Years  $\nu + 5$  Years  $\nu$  Run 1.66MW
- 270kt Water Cherenkov Detector each

@ Korea, Kamioka



## Scenario 3



$\sin^2(2\theta_{13}) = 0.04$ , neutrino, normal hierarchy, Scenario B

F.Dufour@NP08

(study is initiated by M.Ishitsuka et. al. hep-ph/0504026)

# Superbeams in Europe

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

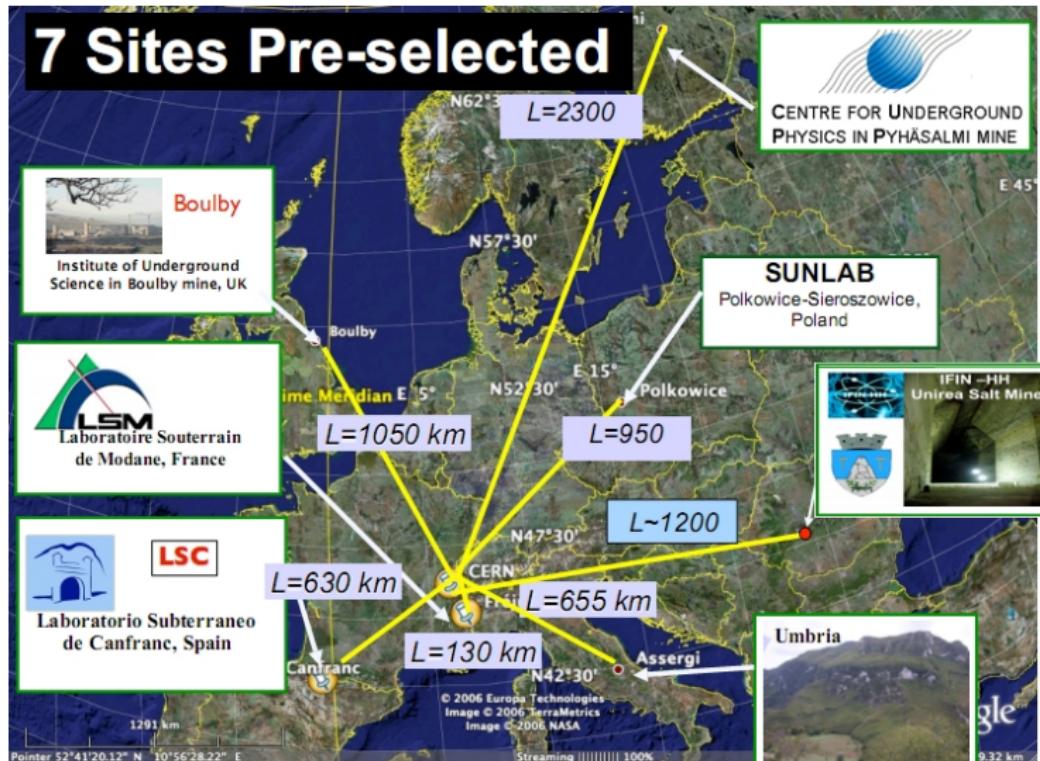
Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary



# Summary and Conclusions

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

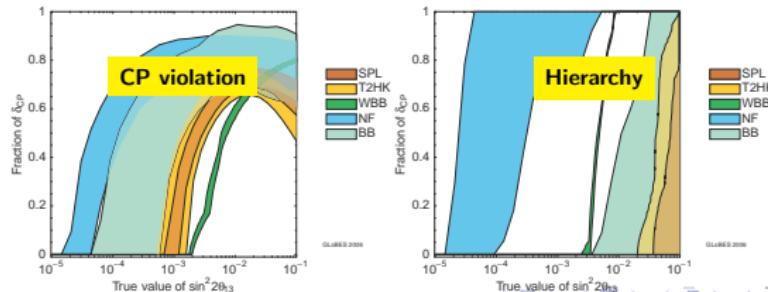
*3 flavor neutrino mixing is now well established.*

**BUT- what we dont know is even more important:**

- What is the mass of  $\nu_\mu$  (see arXiv:0908.2158)?
- How small is  $\sin^2 2\theta_{13}$ ? Is it close to the current limit (0.1) or is it very small? Is it 0?
- Is there CP violation (and LFV) in the lepton sector?
- What is the mass hierarchy?
- Are there only 3 generations of leptons?

*Next. gen. reactor and accelerator  $\nu$  expts determine if  $\sin^2 2\theta_{13} > 0.005$  and can measure  $\delta_{cp}$  and the mass hierarchy for  $\sin^2 2\theta_{13} \geq 0.01$ .*

**Neutrino factories and beta beams can push further, arXiv:0712.0909 :**



Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

## EXTRA SLIDES FOR DISCUSSION

# Sensitivity vs Exposure

Accelerator  
Neutrinos in  
the 21<sup>st</sup>  
Century

Mary Bishai  
Brookhaven  
National  
Laboratory

Accelerator  
neutrinos and  
neutrino  
mixing

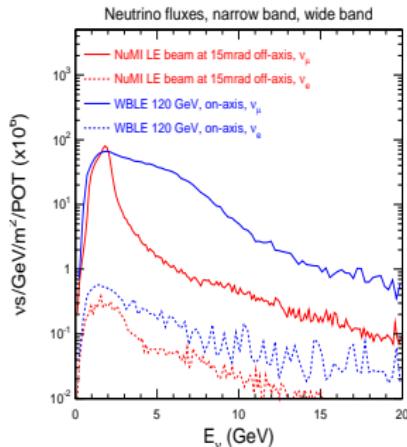
Short baseline  
accelerator  
expts

CP violation  
and the mass  
hierarchy

Future long  
baseline expts  
DUSEL/LBNE  
Neutrino Expts.  
in Japan  
Superbeams in  
Europe

Summary

*The potential physics reach  
from studies with the 120  
GeV WBLE-DUSEL at  
1300km using a LAr  
detector, the NO $\nu$ A\*  
experiment and the T2KK  
experiment:*



From hep-ph/0703029:

